Sensitivity Analysis of an Engineered Barrier System Model for the Proposed Repository System in the United States

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PSAM 7 / ESREL '04 Abstract

A technique is proposed to identify the most important model elements controlling radionuclide release rate from the engineered barrier system of the proposed high-level waste repository at Yucca Mountain, Nevada, USA. The technique is based on the partitioning method (Pensado et al., 2002) and the principal component decomposition suggested by McKay and Campbell (2002). McKay and Campbell discussed an approach to sensitivity and importance analysis when the output variables are functions (e.g., radionuclide release rate as a function of time). In this approach, output functions from a statistical model, representing output uncertainty, are treated as vectors. Vectors are constructed by evaluating the output function for each realization at particular abscissae values. Spectral decomposition of the covariance matrix of these output vectors produces a complete basis of the vector space. Projection of the realization "functions" along the eigenvectors produces a set of coefficients that can be used with standard sensitivity analysis techniques. The sensitivity and importance analysis problem is greatly simplified if the "functions" can be written as a linear combination of few eigenvectors (i.e., few projection coefficients suffice to summarize the whole function). In this study, radionuclide release rates from the engineered barrier system were evaluated at more than 200 timesteps to construct the function vectors. The first 10 eigenvectors (i.e., those eigenvectors with eigenvalues of largest magnitude) sufficed to reproduce the bulk shape of the release rate versus time curves.

The partitioning method (Pensado et al., 2002) was used to identify the parameters affecting most the magnitude of the projection coefficients of the radionuclide release rate as a function of time computed with the Total-system Performance Assessment (TPA) Code Version 4.1j (Mohanty et al., 2002). The TPA code is executed in Monte Carlo mode using the Latin Hypercube method to sample values of stochastic input parameters (currently more than 300). Besides producing dose versus time curves, the code yields estimates of radionuclide release rates at key model interfaces of the system, such as the engineered barrier system, unsaturated zone, and saturated zone. Only information related to the engineered barrier system was analysed in this paper. In the partitioning method, the sampled parameter values (we considered 500 samples) were split into two sets, depending on whether the projection coefficient along the first eigenvector was positive or negative for a particular realization. The complementary distribution function of the set with the smallest cardinality was derived and compared to the cumulative distribution function of the complete sampled-parameter population. The intersection of these two curves along the probability axis, p, was computed. A graphical example of the determination of p is shown in Figure 1. If the subset is truly random, p must be close to 0.5. The distance away from 0.5, $|p-0.5|$, is a measure of the parameter importance on the output (in this case, the projection coefficient along the first principal direction). A positive value of the p-0.5 statistic indicates a positive correlation between the parameter and the projection coefficient. If the distance $|p-0.5|$ is significant and p-0.5 is positive, then those realizations with large values of the parameter also produce relatively large radionuclide release rates from the engineered barrier system. If p-0.5 is negative, then realizations with small values of the parameter are also the realizations having relatively large radionuclide release rates. The standard deviation of the $|p-0.5|$ statistic, when a subset with n elements is drawn in truly random manner from any arbitrary distribution, is

$$\sigma_n = \frac{0.246}{\sqrt{n}} \qquad [1]$$

We considered that $|p\text{-}0.5|$ was significant if $|p\text{-}0.5| \geq 2\text{-}\sigma_n$. In other words, parameters with $|p\text{-}0.5| < 2\text{-}\sigma_n$ were regarded as noninfluential on the particular projection coefficient. The most important parameters were identified by sorting the $|p\text{-}0.5|$ statistic for each of the parameters, for the first 10 projection coefficients. Monte Carlo runs with 500 realizations were considered in this analysis.

Results indicate that model parameters that most affect the radionuclide release rate from the engineered barrier system are related to variables controlling the radionuclide leaching rate from spent nuclear fuel rods, the amount of water available for radionuclide transport, solubilities of radionuclide-bearing solids, and variables controlling the rate of degradation of waste package and drip shield components. This sensitivity analysis method is particularly suitable to study the importance of parameters during particular periods of repository operation (e.g., from 0 to 10,000 years and from 10,000 to 100,000 years) yielding different results for each period. In this paper, the radionuclide release rate from the engineered barrier system is used as an intermediate indicator of repository performance and risk-significance, complementing other metrics required by the United States regulation such as the maximum of the mean dose versus time in 10,000 years.

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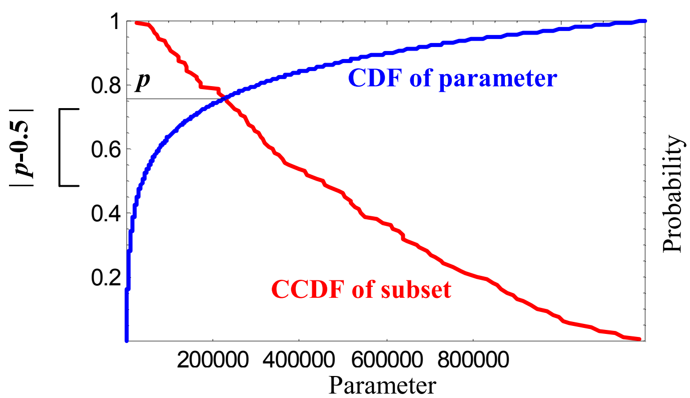

Figure 1. Example of approach to compute the $|p\text{-}0.5|$ statistic.

References

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